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Metallurgical Calculations: Balance Sheet of the Blast Furnace

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Metallurgical Calculations.

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BALANCE SHEET OF THE BLAST FURNACE.

As the most important factor in the production of the most important metal, the blast furnace is the most important furnace or piece of metallurgical apparatus in the world. It is, therefore, proper that we should commence a series of articles on the application of metallurgical principles and calculations to the metallurgy of iron, by a discussion of the blast furnace; and since this discussion, to be complete, must include a wide range of topics, we will commence with the simplest, viz.: the balance sheet of materials entering and leaving the furnace. Later we can discuss the balance sheet of heat entering in, developed within and leaving the furnace, the reactions taking place in the furnace, the action of hot and of dried blast, the calculation of the proper constituents of the charge, the temperatures attained before the tuyeres, unused combustible energy of the gases, efficiency of the hot-blast stoves, and other interesting and practically valuable factors in the running of the furnace.

The blast furnace may be regarded from several points of view; we will mention two. First, it may be regarded as a huge gas producer, run by hot, forced blast, in which the incombustible portions of the contents are melted down (with a little unburnt carbon) to liquid metal and slag, and are run out beneath, while the gaseous products pass upwards through 50 to 100 feet of burden, and escape above. The escaping gases are primarily of the composition of producer gas, with some of its carbonous oxide changed to CO^2 by the oxygen abstracted from the burden, with some CO^2 added from the decomposition of the carbonates of the charge, and with the usual increment of moisture from the charge and volatile matter (if any) from the distillation of the fuel. From this point of view, the blast furnace is a huge gas producer, giving a rather inferior quality of combustible gas in very large quantities, and incidentally reducing to metal and slag the burden of iron ore and flux (limestone) which is put in with the fuel. The treatment of the furnace as a metallurgical problem may then proceed as the discussion of a gas producer, with the composition of the gas produced somewhat modified by the amount of oxygen given up to the gas by the reducible portions of the charge of the furnace.

The other viewpoint is to regard the furnace as primarily an apparatus for deoxidizing or reducing iron ore, for which purpose the ore is charged with sufficient carbonaceous fuel to do two things, viz.: to abstract all the oxygen from the reducible metallic oxides, and to furnish enough heat, or high enough temperature, to melt down to superheated liquids the pig iron and slag (combinations of irreducible metallic oxides) formed. In this view, the fuel must supply the reducing energy and the melting-down or smelting requirements; the first by acting upon the metallic oxides at a red to white heat, and abstracting their oxygen; the second, by being burned at the foot of the furnace by hot air blast, and there generating the heat and higher temperatures necessary for the smelting down of the already reduced materials.

MATERIALS CHARGED AND DISCHARGED.

The materials put into a blast furnace may all be classed under four heads:

Fuel .... }
Iron ore .... } Charged at the throat.
Fluxes .... }
Blast .... Blown in at the tuyeres.

The materials discharged from the furnace may be classed under four heads also:

Pig iron .... }
Slag .... } Tapped from the crucible.
Gases .... }
Dust .... } Passing out at the top.

We will discuss the resolution of each of the four materials charged into the four avenues of escape.

FUEL.

The fuel used is sometimes charcoal, but in the great majority of cases coke, with perhaps some raw bituminous coal or anthracite coal, or in a few cases all raw bituminous coal. The composition of these fuels consists of moisture, volatile matter, fixed carbon, sulphur and ash consisting of silica, lime, iron, alumina, alkalies, etc.

The moisture is driven off near the top, and goes into the gases as moisture. The volatile matter is expelled near to the top; almost all of it goes unchanged into the gases, but part of the hydrocarbons thus expelled may be decomposed and deposit fixed carbon on the iron oxides, etc., surrounding them. This carbon, however, will take up oxygen from the charge lower down in the furnace, and thus eventually pass into the gases as CO or CO^2. We can, therefore, assume without error that all the volatile constituents of the fuel pass into the gases, but cannot be certain in exactly what state of combination, except as regards the moisture. It will be quite exact if we know the ultimate composition of the volatile matters of the coal, as so much carbon, hydrogen, oxygen, nitrogen, sulphur, etc., to charge them thus entirely to the gases.

The fixed carbon all finds its way ultimately into the dust or the gases, either as CO, CO^2, CH^4 or HCN, or alkali cyanides, excepting the amount represented by the carbon in the pig iron. Subtracting the carbon in the pig iron from the total fixed carbon in the fuel, the difference can safely be put down as entering the gases or being in the dust carried away by the gases.

The sulphur in the fuel has a more varied history. When it is partly present in the form of iron pyrites, some may go into the gases as sulphur vapor, and eventually be burned to SO^2 when the gases are burned; another part may be oxidized in the furnace itself to SO^2, and as such appear in the gases; the rest, along with organic sulphur, passes either into the slag or the pig iron. Sulphur passing into the slag seems to do so as calcium sulphide, CaS, formed by some such reaction as

$$CaO + C + FeS = CaS + CO + Fe$$

or, if the sulphur was present in the fuel as gypsum,

$$CaSO^4 + 4C = CaS + 4CO$$

The amount of sulphur going into the iron depends really upon the opportunity for it to go into the slag. If the temperature of the furnace at the tuyeres is very high, and especially if the slag is low in silica, sulphur will keep out of the iron and go into the slag, to the extent of ten or twenty times as much being in the slag as in the iron; but if the temperature is low and the slag rich in silica the reverse may be the case. A high temperature and a high percentage of lime in the slag are the blast furnace manager's means of keeping down the sulphur in the iron, although high magnesia or high alumina are also efficacious. In casting up the balance sheet it can be assumed that when using coke or charcoal all the sulphur of the fuel goes either into the slag or the iron, and knowing from the analysis of the pig iron made how much goes into it, the rest can be calculated as going into the slag as CaS. If raw coal is used, it is uncertain how much sulphur goes into the gases, and an exact analysis of either the slag or gases, for sulphur, in addition to that of the pig iron, would be necessary to fix its distribution.

The ash of the fuel counts in with the other incombustible ingredients of the charge. Some of the silica in it may be reduced to silicon, and some of the CaO to Ca, to form CaS; while most of the iron will pass into the pig iron. It is in most cases uncertain whether the silicon in the pig iron comes at all from the fuel ash, so it is usual to assume it as coming from the silica of the ore only; as to the iron, it is best to assume it all reduced to the metallic state, as is probably always the case.

Besides all these avenues of escape for the constituents of the fuel, it is sometimes necessary to take into account the possibility of some of it, in fine particles, being carried out of the furnace bodily with the outgoing gases. If the amount of this in the dust is determined, it must be subtracted *in toto* from the fuel charged, and then the remainder distributed as just discussed.

Illustration: A blast furnace is charged, per 1,000 kilos. of pig iron produced, with 925 kilos. of coke, containing by analysis: Fixed carbon, 86 per cent; volatile carbon, 2; hydrogen, 1; oxygen, 0.5; nitrogen, 0.5; sulphur, 1.0; iron, 2; silica, 5; lime, 1; moisture, 1. The pig iron contains 3.5 per cent of carbon and 0.1 per cent of sulphur. The dust carries 15 kilos. of dry coke per metric ton of pig iron. Required the distribution of the coke in the furnace per ton of pig iron made:

Charge			*Pig Iron*	*Slag*	*Gases*	*Dust*
Coke	925.0	kilos.				
Dust	15.0	"	....	....	....	Coke 15
Fixed C	782.6	"	C 35.0	....	C 747.6	....
Volatile C	18.2	"	....	....	C 18.2	....
H	9.1	"	....	....	H 9.1	....
O	4.5	"	....	....	O 4.5	....
N	4.5	"	....	....	N 4.5	....
S	9.1	"	S 1.0	S 8.1	....	....
Fe	18.2	"	Fe 18.2	....	....	....
SiO^2	45.5	"	....	SiO^2 45.5	....	....
CaO	9.1	"	....	CaO 9.1	....	....
H^2O	9.3	"	....	....	H^2O 9.3	....

ORE.

Whatever the varieties of ore used they can be averaged together, so as to get the average composition of the ore charged. Then, knowing its weight per unit of pig iron made, the distribution into pig iron, slag, gases and dust can be made.

There may, first of all, be blown out as ore dust up to 25 per cent of the ore charged. This must be first deducted as dry ore and then the rest distributed to pig iron, slag and gases.

The moisture of the ore, also any carbonic acid, may be considered as going over bodily into the gases. The sulphur may partly go into the gases if present as iron pyrites (this amount would have to be checked by an analysis of the gases for sulphur or hydrogen sulphide), but mostly into the slag as CaS. Some of it may be put down as going into the pig iron, if the sulphur in the fuel does not account for all that appears in the analysis of the iron. The iron oxides present must be assumed reduced to metallic iron sufficient to furnish the iron in the pig iron from its analysis; the excess, if any, is put down as going into the slag as FeO; all the oxygen given off (the difference between the weight of iron oxide in the ore and the sum of iron going in the pig iron and ferrous oxide passing in the slag) goes to the gases. If there is not enough iron in the ore to account for all in the pig iron, then none is assumed to go into the slag.

The manganese oxides in the ore furnish the manganese in the pig iron, the excess going into the slag as manganous oxide MnO, the oxygen (by difference) goes to the gases. The proportion of manganese reduced to metal increases with the temperature at which the furnace is run and as the slag is less siliceous. The amount reduced is known, however, only by the analysis of the pig iron.

Zinc in the ore is partly found as ZnO in the slag, and partly as flakes of white zinc oxide in the gases, which latter partly deposit in the dust catcher and are partly carried by the current of gases into the stoves and under the boilers. The relative amounts going into slag and gases can be best controlled by analysis of the slag.

Copper, silver, gold, nickel, cobalt, phosphorus, antimony and arsenic are almost completely reduced into the pig iron; careful analysis of the latter will show exactly to what extent, but without this careful analysis they may be assumed to pass completely into the iron. Lead is mostly carried out as fume, a small amount passes into the pig iron, and, if present in quantity, a large amount may collect as metallic lead beneath the pig iron and, if it can, soak into the foundations of the furnace.

Alumina usually passes completely, as such, into the slag. When present in large amount, producing a slag rich in alumina, and with very hot blast, the pig iron may contain as much as 1 per cent of aluminium, the oxygen thereof passing into the gases. Magnesia may be assumed as passing completely into the slag; none is reduced. Lime goes into the slag, except a not-unimportant quantity which is reduced by carbon in the presence of sulphur compounds, and forms CaS, its oxygen passing into the gases; a very small amount may go as calcium into the pig iron. Alkaline metals partly go into the slag, while some may pass into the gases as alkaline cyanides. Titanium oxide, tungsten oxide, chromium oxide and the oxides of molybdenum, uranium, vanadium are sometimes reduced in small amounts, the more the hotter the furnace is run and the more basic the slag, while the bulk of them passes into the slag as the lowest oxide which each is capable of forming.

Silica mostly goes into the slag as SiO^2, but a portion is always reduced to silicon in the pig iron. The amount reduced is greater the hotter the furnace is run, the more slowly it is run, and the more siliceous the slag. In some cases as much as one-quarter of all the silica going into a furnace is reduced to silicon. It is probably reduced only by carbon dissolved in iron at the lower part of the furnace. The oxygen of the silica reduced goes into the gases.

Illustration: 1956.8 kilograms of ore is charged into a furnace per metric ton of pig iron made. The ore analyzes: Fe^2O^3, 71.43 per cent; SiO^2, 14,24; CaO, 2.05; MgO, 1.51; MnO^2, 4.15; SO^3, 1.40; H^2O, 5.00; Cu^2O, 0.22 per cent. The pig iron contains 93.03 per cent iron, 3.27 carbon, 1.20 manganese, 0.08 sulphur, 0.40 copper, 2.02 silicon. Assume the dry ore dust to weigh 4 per cent of the weight of ore charged, and that there is no sulphur found in the gases, but all the sulphur in the pig iron comes from the fuel. Cast up the distribution of the ore:

Charge			*Pig Iron*	*Slag*	*Gases*	*Dust*
Ore	1956.8	kg.				
Dust	78.1	"	....	....	....	Ore 78.1
Fe^2O^3	1339.2	"	Fe 930.3	FeO 9.1	O 499.8	....
SiO^2	267.0	"	Si 20.2	SiO^2 223.6	O 22.2	....
MnO^2	77.8	"	Mn 12.0	MnO 48.0	O 17.8	....
Cu^2O	4.1	"	Cu 3.6	....	O 0.5	....
CaO	38.4	"	....	{CaO 20.1 / Ca 13.1}	.... / O 5.2	....
MgO	28.3	"	....	MgO 28.3	....	....
SO^3	26.3	"	....	S 10.5	O 15.8	....
H^2O	97.6	"	....	....	H^2O 97.6	....

In calculating the above we note that the dust is dry, and weighs 4 per cent of the ore, making 78.1 kilos. of dry dust, representing 82 kilos. of moist ore, leaving 1874.8 kilos. of moist ore to be distributed, plus the 3.9 kilos. of water from the dust, which also goes into the gases. This 1874.8 kilos. contains the weights given, calculating from its analysis. The 1339.2 kilos. of Fe^2O^3 contains 937.3 kilos. of iron; but there are only 930.3 kilos. in the ton of pig iron, therefore the other 7.0 kilos. must go into the slag as $7.0 \times \frac{72}{56} = 9.1$ kilos. of ferrous oxide, while $1339.2 - (930.3 + 9.1) = 499.8$, the weight of oxygen going into the gases. The 267.0 kilos. of silica contains 124.6 kilos. of silicon, but there are only 20.2 kilos. in the pig iron, therefore, 104.4 kilos. must remain unreduced, passing into the slag as $104.4 \times \frac{60}{28} = 223.6$ kilos. of silica, while $267 - (20.2 + 223.6) = 22.2$ kilos. of oxygen goes into the gases. Another, and equally logical procedure, is to start with the 20.2 kilos. of silicon in the pig iron, which must have required $20.2 \times \frac{60}{28} = 42.4$ kilos. of silica to furnish it, yielding $42.4 - 20.2 = 22.2$ kilos. of oxygen to the gases, and leaving $267.0 - 42.4 = 223.6$ kilos. of silica unreduced to go into the slag.

The 12.0 kilos. of manganese in the pig iron would be reduced from $12.0 \times \frac{87}{55} = 19.0$ kilos. of MnO^2, furnishing, therefore, 7.0 kilos. of oxygen to the gases, and leaving $77.8 - 19.0 = 58.8$ kilos. of MnO^2 to go into the slag as MnO. The molecular weights of MnO and MnO^2 being respectively 71 and 87, there is $58.8 \times \frac{71}{87} = 48.0$ kilos. of MnO going into the slag, while 10.8 kilos. more of oxygen will be supplied to the gases, making altogether $10.8 + 7 = 17.8$ kilos. of oxygen given up by the MnO^2. The 4.1 kilos. of Cu^2O contain 3.6 kilos. of copper, all of which enters the pig iron and contributing 0.5 kilos. of oxygen to the slag.

The 38.4 kilos. of CaO must supply enough Ca to form CaS with the S of the SO^3. The latter quantity is $26.3 \times \frac{32}{80} =$ 10.5 kilos., to supply which there is needed $10.5 \times \frac{40}{32} =$ 13.1 kilos. of calcium. The latter will be supplied by $13.1 \times \frac{56}{40} = 18.3$ kilos. of CaO, furnishing 5.2 kilos. of oxygen to the gases, and leaving $38.4 - 18.3 = 20.1$ kilos. of CaO unreduced to go into the slag. The MgO in the ore goes directly into the slag. The oxygen of the SO^3 goes into the gases. The 5 per cent of water of the whole quantity of ore charged goes into the gases as vapor.

FLUX.

The flux is used for the purpose of making a fusible slag with the slag-forming ingredients contributed by the ore and fuel. If we consider the distribution of ore and fuel given in the preceding illustrations we see that the chief material to be fluxed is silica, with smaller quantities of FeO, MnO, CaO, MgO and CaS. The cheapest and most available material to flux silica is limestone, the slag formed being a silicate of lime, magnesia and alumina, with CaS and smaller quantities of other basic oxides. We will not discuss at present the considerations governing the amount of flux used, since this is a calculation requiring separate treatment, as the proper working of the furnace depends fundamentally upon it. We may remark here that enough flux must be used to make an easily fusible fluid slag, rich enough in lime, magnesia or alumina to carry away satisfactorily the bulk of the sulphur, and so produce good pig iron.

The flux usually contains CaO, MgO, Al^2O^3, SiO^2, FeO, CO^2 and H^2O. Its H^2O and CO^2 are driven off in the upper third of the furnace, and may be put down as going as such into the gases. The FeO may be reduced if the slag is very clean, but under ordinary conditions may be put down as all going into the slag, unless in quite large amount, because the iron in ore and fuel usually supplies the total weight of iron in the pig iron. The silica and alumina may be carried over bodily into the slag. The magnesia can be put at once into the slag, but the lime cannot in many cases be treated that way, because quite frequently some is needed to supply calcium for the sulphur of the fuel. In the fuel previously illustrated, for instance, there is not enough CaO present to furnish Ca for the S, whence it follows that some CaO from the flux will be needed to make up the deficit. We may, in such a case, either consider all the CaO of the fuel to form CaS with part of the sulphur, and then take enough CaO from the flux to unite with the remainder. Or, it is equally permissible to take all the CaO necessary to furnish Ca to all the sulphur of the fuel, and to let the CaO of the fuel figure as passing entirely into the slag. The latter requires a little less calculation.

Illustration: A blast furnace receives 503 kilos. of limestone flux per metric ton of pig iron made, which analyses CaO, 29.68 per cent; MgO, 20.95; SiO^2, 3.07; Al^2O^3, 2.66; FeO, 0.48; CO^2, 42.66; H^2O, 0.50 per cent. Assume 8.1 kilos. of sulphur in the fuel, for which the flux must provide calcium. Required the distribution of the flux, assuming it to make no dust:

Charge		*Pig Iron*	*Slag*		*Gases*	
Flux	503.0 kg.					
CaO	149.3 "	....	Ca	10.1	O	4.1
			CaO	135.1		
MgO	105.4 "	....	MgO	105.4	....	
SiO^2	15.4 "	....	SiO^2	15.4	....	
Al^2O^3	13.4 "	....	Al^2O^3	13.4	....	
FeO	2.4 "	....	FeO	2.4	....	
CO^2	214.6 "	....	....		CO^2	214.6
H^2O	2.5 "	....	....		H^2O	2.5

The only calculation needed above is that 8.1 kilos. of sulphur require $8.1 \times \frac{40}{56} = 10.1$ kilos. of calcium, which would be furnished by $10.1 \times \frac{32}{40} = 14.2$ kilos. of lime, leaving 4.1 kilos. of oxygen to go into the gases and 135.1 of lime to go into the slag.

BLAST.

The remaining item needed to complete the balance sheet is the amount of blast. This may be roughly estimated by obtaining the piston displacement of the blowing engines, and assuming a coefficient of delivery into the furnace. This is very rough, because the efficiency is not known, and may vary anywhere between 0.5 and 0.95. Another rough approximation may be obtained by observing the pressure of the blast, its temperature, the back pressure in the furnace, and knowing the area of the tuyeres, and assuming a coefficient of contraction of the hot air jet as it emerges from the tuyeres. Here, again, are several uncertain factors, and the coefficient may vary between 0.9 and 0.98. Calculations on this basis are very rough.

The only satisfactory way to determine the blast is to carefully analyze the gases, determining carefully all the carbon, oxygen and nitrogen which they contain. Since the carbon comes only from the charges, the amount of gas produced per unit of pig iron made becomes known, and thence the oxygen and nitrogen contained in them. These, minus the oxygen and nitrogen coming from the solid charges, leave the oxygen and nitrogen which must have come from the blast. The oxygen in the blast, minus $\frac{3}{10}$ the nitrogen, gives the oxygen entering as water vapor; but this last calculation is not so satisfactory as to observe the atmospheric conditions, and calculate the air and moisture on the basis of the contained nitrogen.

The blast contains oxygen, nitrogen and moisture. All its constituents pass into the gases, being put down as so much oxygen, nitrogen and hydrogen. Just how much of that hydrogen gets into the gases as free hydrogen and how much as water vapor is not known. Argon and other rare gases in the blast are counted and treated as nitrogen. The carbonic acid of the air is present relatively in such a small amount that it can be neglected, as far as all ordinary calculations are concerned.

Problem 51.

A blast furnace at Herräng, Sweden, is run on ore briquettes made by pressing and calcining fine concentrates. The analyses of briquettes, charcoal and limestone flux are as follows (see Journal Iron and Steel Institute, I., 1904):

	Briquettes	*Limestone*		*Charcoal*	
Fe^2O^3	85.93		0.18		0.32
FeO	3.96		.....	C	80.31
SiO^2	5.50		3.14		0.19
MnO	0.63		.....	N	.08
Al^2O^3	0.76		0.32	O	3.54
CaO	2.23		53.74		0.89
MgO	0.97		0.17		0.10
P^2O^5	0.006		0.006		0.0068
S	0.010		0.001		0.0170
Cu	0.007	CO^2	42.42	H^2O	14.04
				K^2O	0.50

The pig iron contains phosphorus, 0.012 per cent; sulphur, 0.007; manganese, 0.025; silicon, 0.60; carbon, 2.70; iron, 96.656. There is used in charging the furnace:

Briquettes	....	1,190 pounds
Limestone	....	90 "
Charcoal	....	530 "

And the fuel consumption is 682 pounds of charcoal per 1,000 pounds of pig iron made.

The gases at the throat (dried) analyze: N^2, 57.3 per cent; CO, 23.1; CO^2, 14.8; H^2, 4.3; CH^4, 0.5 (Rinman). Assume blast dry. Dust in gases neglected. Required: (1) A balance sheet of materials entering and leaving the furnace, per 1,000 pounds of pig iron made. (2) The percentages of iron, manganese, silicon, sulphur and phosphorus going into the furnace, which go into the pig iron.

Solution: (1) Balance Sheet

Per 1000 of Pig Iron Made.

	Charges		*Pig Iron*		*Slag*		*Gases*	
Ore, 1530.2 lbs.	Fe^2O^3	1314.9	Fe	920.4	....		O	394.5
	FeO	60.6	Fe	46.2	FeO	1.2	O	13.2
	SiO^2	84.2	Si	6.0	SiO^2	69.6	O	8.6
	MnO	9.6	Mn	0.25	MnO	9.3	O	0.1
	Al^2O^3	11.6	....		Al^2O^3	11.6	....	
	CaO	34.1	....		CaO	34.0	O	0.03
	MgO	14.8	....		MgO	14.8	....	
	P^2O^5	0.092	P	0.04	....		O	0.05
	S	0.153	S	0.07	CaS	0.19	....	
	Cu	0.11	Cu	0.11	....		....	
Limest. 115.8 lbs.	Fe^2O^3	0.2	....		FeO	0.2	O	0.02
	SiO^2	3.6	....		SiO^2	3.6	....	
	Al^2O^3	0.4	....		Al^2O^3	0.4	....	
	CaO	62.2	....		CaO	62.2	O	0.00
	MgO	0.2	....		MgO	0.2	....	
	P^2O^5	0.007	P	0.003	....		O	0.00
	S	0.001	....		CaS	0.00	....	
	CO^2	49.1	....		....		CO^2	49.1
Charcoal, 682 lbs.	C	547.7	C	27.0	....		C	520.7
	N	0.5	....		....		N^2	0.5
	O	24.1	....		....		O	24.1
	Fe^2O^3	2.2	....		FeO	2.0	O	0.2
	SiO^2	1.3	....		SiO^2	1.3	....	
	CaO	6.1	....		CaO	5.9	O	0.06
	MgO	0.7	....		MgO	0.7	....	
	P^2O^5	0.046	P	0.020	....		O	0.03
	S	0.116	....		CaS	0.25	....	
	K^2O	3.4	....		K^2O	3.4	....	
	H^2O	95.8	....		....		H^2O	95.8
Blast	O^2	557.7	....		....		O	557.7
	N^2	1859.1	....		....		N^2	1859.1
	Totals	4,744.0		1,000.0		220.8		3,543.7

(2) The total iron in the charge is 969.2 kilos., while that in the pig iron is 966.6; the efficiency of the reduction of iron is therefore 99.7 per cent.

The total manganese in the charge is $9.6 \times \frac{55}{71} = 7.4$ kilos., of which only 0.25 gets into the pig iron, or 3.4 per cent.

The total silica charged is 89.1 kilos., representing 41.6 kilos. of silicon, of which 6.0 kilos. enters the pig iron, or 14.4 per cent.

The sulphur charged is 0.270 kilos., of which the pig iron contains 0.07, or 25.9 per cent.

The phosphorus charged is 0.063 kilos., while the analysis of the pig iron shows in it 0.12 kilos. It is thus evident that all the phosphorus goes into the pig iron; for while the analysis shows more phosphorus in the pig iron than was put into the furnace, yet the divergence is evidently due to segregation or concentration of phosphorus in the sample taken, and the practical conclusion is that all the phosphorus in the charge finds its way into the pig iron.

NOTES ON THE BALANCE SHEET.

The Fe^2O^3 of the ore is assumed all reduced, because the 920.4 kilos. of iron in it is less than the 966.6 kilos. of iron known to be in the 1,000 kilos. of pig iron from its analysis. The FeO, however, cannot be assumed all reduced, because it would furnish 47.1 kilos. of iron, and there is only 966.6 — 920.4 = 46.2 kilos. of iron yet to be supplied. We, therefore, put down 46.2 kilos. of iron as going to the pig iron, thus furnishing all the iron in the pig iron, and leaving 0.9 kilos. of iron to go over into the slag as 1.2 kilos. of FeO. Having thus allowed for all the iron in the pig iron, the Fe^2O^3 in the limestone and fuel must be assumed as passing entirely into the slag as FeO.

The 6 kilos. of silicon in the pig iron is put down as coming entirely from the SiO^2 of the ore, of which 14.6 kilos. is thus used up, leaving 15.6 kilos. to go into the slag. The SiO^2 of flux and fuel must then be regarded as passing entirely into the slag.

The 0.25 of manganese in the pig iron comes from the MnO of the ore, requiring 0.35 of MnO, and leaving 9.3 of MnO to go into the slag.

The Al^2O^3 and MgO of ore, flux and fuel go bodily into the slag.

The sulphur in the ore, 0.153 kilos., is more than enough to supply the 0.07 kilos in the pig iron. We, therefore, put down 0.07 kilos. as going into the pig iron, supplying all the latter contains, and calculate the remaining 0.083 kilos. to CaS going into the slag. The CaO necessary to furnish this calcium is 56 for every 32 of sulphur (CaO = 56, S = 32), or 0.14 kilos., which, therefore, must be deducted from the 34.1 kilos. of CaO present in the ore. The oxygen of this 0.14 kilos. of CaO finds its way into the gases.

The 0.092 kilos. of P^2O^5 present in the ore contain only 0.04 kilos. of phosphorus, and since the pig iron contains, from its analysis, 0.12 kilos., we may assume all of this going into the pig iron. The same remarks are true of the P^2O^5 in flux and fuel; altogether, they come somewhat short of supplying all the phosphorus in the pig iron, and are, therefore, considered as completely reduced. The copper goes entirely into the pig iron, although not given in the analysis.

The Fe^2O^3 of the limestone must be transferred entirely as FeO to the slag, since all the iron needed for the pig iron has been already provided. The same is true of the Fe^2O^3 of the fuel; and an analogous statement applies to the SiO^2 and sulphur of both flux and fuel. The sulphur of the fuel does not produce an amount of CaS which counts in significant figures, and the CaO required is likewise insignificant, as is also the oxygen thus furnished the gases. In such cases, instead of ignoring the item altogether, or putting down wholly insignificant quantities, the amounts are expressed as 0.00, denoting no significant amount.

The fixed carbon of the fuel, only, furnishes the carbon in the pig iron, the rest going into the gases. The blast is calculated as follows:

Carbon in CO^2 of flux $= 49.1 \times \frac{12}{44}$	=	13.39 kilos.
Carbon in gases from fuel	=	520.70 "
Carbon in gases altogether	=	534.09 "
Carbon in 1 cu. meter of gas $(0.231 + 0.148 + 0.005) \times 0.54$	=	0.20736 "
Volume of gas per 1,000 of pig iron $= 534.09 \div 0.20736$	=	2575.6 m^3
Nitrogen in this gas $= 2575.6 \times 0.573$	=	1475.9 "
Weight of nitrogen $= 1475.9 \times 1.26$	=	1859.6 kilos.
Nitrogen from fuel	=	0.5 "
Nitrogen from blast	=	1859.1 "
Oxygen from blast $= 1859.1 \times 0.3$	=	557.7 "